The Effect of the Nonuniform Magnetic Field on the Instability of Plasma Wave

Mataharu TANAKA*, Toshitaka IDEHARA*, Yoshio ISHIDA*

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The amplification factor of the space charge wave of beam excited by the reactive medium instability decreases with the non-uniformity of the magnetic field increased. The anomalous damping of excited wave is observed near the point of local cyclotron resonance, which can be explained by the cyclotron damping of the longitudinal wave propagating obliquely to the field.

1. Introduction

In the uniform magnetic field, the instability in a beam-plasma system has been investigated by many authors[1,2] with a great interest.

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*) Department of Applied Physics.

In the high frequency region where the electron wave plays a main part, the Bernstein waves[3] and the Trevelpiece waves[4] are the most general waves in a magnetized plasma. The formar wave has many branches in the region of higher frequency than the electron cyclotron frequency ω_c, and the latter has a brench in the lower frequency than ω_c. The instability concerned with these waves in a beam-plasma system is the reactive-medium-instability of the space charge wave of beam, in the case where the electron beam is injected parallel to the line of magnetic force.

In this paper, we describe the results of an experimental study of this instability excited in a beam-plasma system magnetized by the nonuniform field. It is shown that the amplification factor of the wave ascribed to the instability decreases with increasing the non-uniformity of magnetic field. Moreover the anomalous damping is investigated near the local cyclotron resonance region.

In section 2, we describe the experimental apparatus and procedures. Section 3. gives the experimental results and disccusions. Our results are summarized in section 4.

2. Experimental Apparatus and procedures

In order to investigate the propagation of waves and the instability of the wave due to the interaction of an electron beam with a plasma, it is desired that a Maxwellian plasma is produced and an electron beam is injected into this plasma, parameters of beam being varied independently on those of plasma. Considering such a requirement, we have set up the apparatus which is consisted of three region, that is, the dc discharge region, the plasma diffsed region (or the beam-plasma system) and the beam generated region as shown in Fig.1. Argon gas of the pressure of about $1\sim2\times10^{-2}$ Torr is fed into the discharge region, and by using a method of differential pumping, the gas pressures of the plasma diffused and the beam generated region are maintained at about $1\sim2\times10^{-3}$ and $0.8\sim1\times10^{-4}$ Torr,respectively. An external magnetic field is applied along the tube axis. The coils are numbered from the right hand side as shown in Fig.1. By controling the current of each coils, various configurations of magnetic field are formed along the plasma diffused region. When the discharge current I_d is varied from 5 to 150 mA,

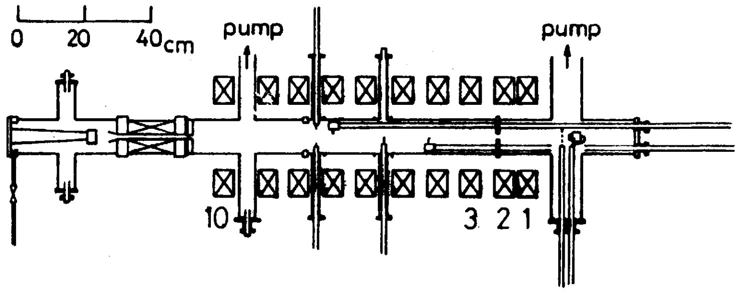

Fig. 1. Experimental apparatus

the plasma density n_p is varied from 5×10^8 to 8×10^{10} cm^{-3} but the electron temperature is constant at about $5\sim10$ eV in the region. The principle of the apparatus is similar to the TP-D machine at the Institute of Plasma Physics, Nagoya University.

An electron beam is produced by the Pierce gun in the beam generated region, and is injected into the plasma diffused region through a hole of 15 mm in diameter. The electron gun is set on the tube axis, and the electron beam is injected parallel to the line of magnetic force. When the acceleration voltage V_b of beam is changed from 50 to 300 V, the cathod current of gun I_{bk} changes from 3 to 20 mA. The electron density of beam n_b is varied from 1.5×10^8 to 4.5×10^8 cm^{3}, but the temperature T_b of beam is constant at about 0.3 eV.

In order to excite and receive the wave, five coaxial probes are inserted in the plasma diffused region, three of them being movable radially and the other two being movable axialy. The signal of the wave excited by a probe is detected using another probe and recorded by the interferometer system. The delay line is used in order to determine the direction of wave propagation.

The example of the non-uniform magnetic field is shown in Fig.2. In this figure, I_1 is the current of five coils from No.1 to No.5, and I_2 is that of the other five coils.

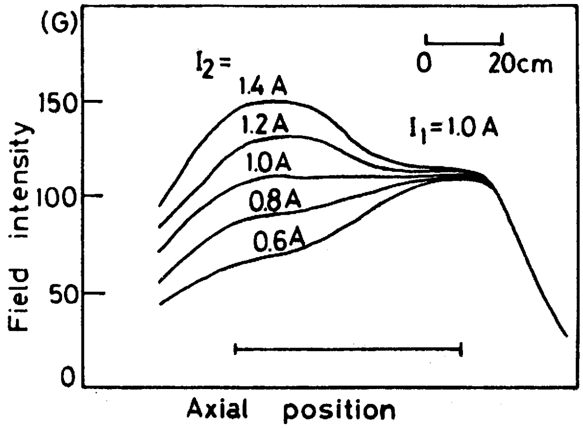

Fig. 2. The intensity distribution of magnetic field.
The solid line shows the region where z probe is swept.

The solid line in the figure shows the region where z probe is swept, that is, the region where the measurement of wave propagation is done.

3. Experimental Results and Discussions

3.1 Reduction of amplification factor due to the nonuniform magnetic field

The pattern of waves propagating axially are recorded as afunction of the separation distance z from the exciting z-probe, by using the interferometer system. The results are shown in Fig.3 (a), with the coil current I_2 as a parameter. This figure shows the wave amplification against the intensity distribution of magnetic field.

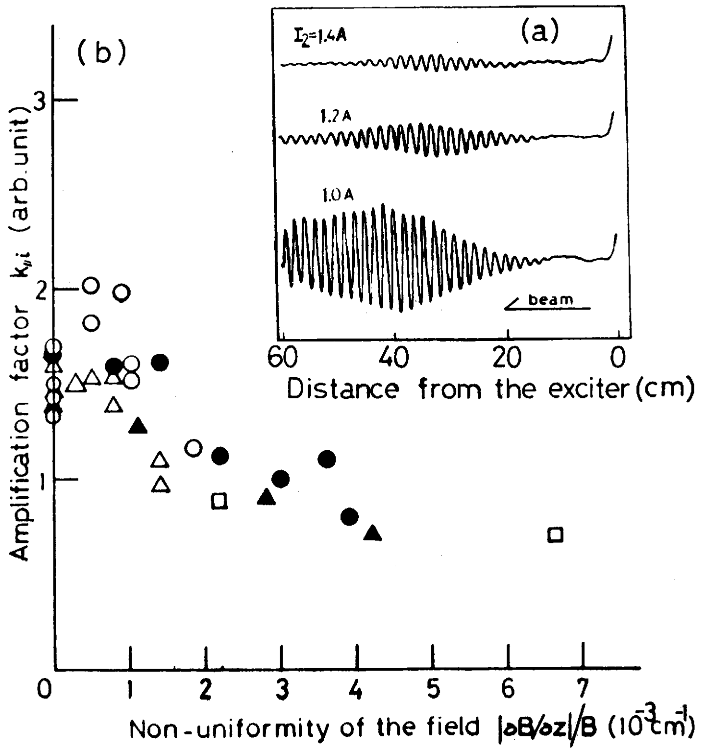

Fig. 3. (a) The wave patterns propagating along the axial direction, with the non-uniformity of field as a parameter. Ar, $p=1\times10^{-3}$ Torr, I_d=8 mA, V_b=180 V, I_1=1.0 A, f=380 MHz.
(b) The amplification factor $k_{//i}$ as a function of $|\partial B/\partial z|/B$

The wave pattern of I_2=1.0 A in the figure is the amplification wave in the uniform magnetic field. It is seen that the amplification of waves is suppressed as the coil current I_2 is increased.

In Fig.3 (b), the amplification factors $k_{//i}$, that is, the imaginary part of $k_{//}$, are plotted as a function of the non-uniformity of magnetic field $|\partial B/\partial z|/B$. As the non-uniformity of magnetic field is increased, the amplification factor decreases gradually.

3.2 Wave damping due to the local electron cyclotron resonance

Next we investigated the effect of the local cyclotron resonance on the excited wave. In order to determine the point of cyclotron resonance, the intensity distribution of magnetic field is calculated and shown in Fig.4. In this figure, I_1 is the current of coils from No.1 to No.8, and I_2 is that from No.9 to No.10. The dotted lines show the intensities of magnetic field corresponding to the cyclotron frequency $\omega_c/2\pi$=390 MHz, 380 MHz and 370MHz, respectively.

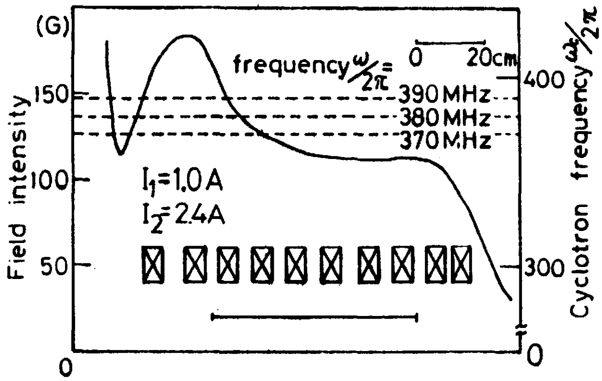

Fig. 4. The intensity distribution of magnetic field. I_1 is the current of coils from No.1 to No.8, and I_2 is that from No.9 to No.10.

At a point of the intersection, the electron cyclotron renonance occurs, and near the point the energy of waves is resonantly absorbed by plasma particles. As the results, the wave is damped strongly. (cyclotron damping) By changing the frequency of excited wave, the situation of the damping region must be moved. To confirm these considerations, we measured the axial wave pattern by using the interferometer system. The results are shown in Fig.5 (a), which corresponds to the configuration of magnetic field shown in Fig.4. For the case of uniform magnetic field, which is shown in the lower pattern of Fig.3 (a), the excited wave is amplified, saturated and, damped slowly. However, for the nonuniform magnetic field which shown in the middle pattern of Fig.5 (a), it is seen that the saturated wave damps rapidly near the

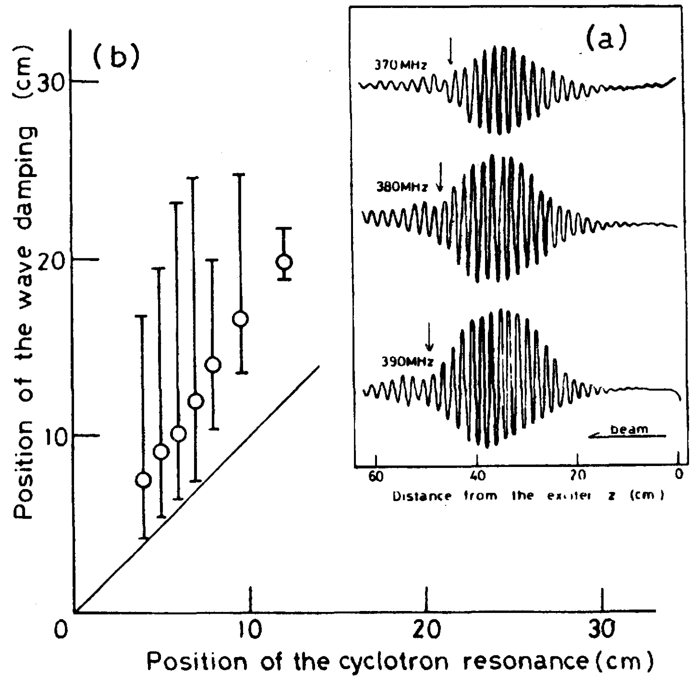

Fig. 5. (a) The cyclotron damping of the wave propagating along the axial direction, with the frequency as a parameter. Ar, $p=1\times10^{-3}$ Torr, $I_d=8$ mA, $V_b=180$ V, $I_1=1.0$ A, $I_2=2.4$ A.

(b) The relation between the position of wave damping and the resonance point.

point indicated by an arrow. This anomalous damping region moves far from the exciter, with increasing the exciting frequency, as shown in the figure. To rearrange these deta, a plot of the anomalous damping region as a function of the cyclotron resonance point corresponding to the exciting frequency, in Fig.5 (b). If the anomalous damping occurs at the cyclotron renonance point, the plots may agree with the solid line in this figure. However they do not lie on the line but shift far from the exciter, because the excited wave begins to damp before it reaches the cyclotron resonance point.

4. Summary

The effect of the non-uniformity of magnetic field on the instability of space charge wave of beam is investigated experimentally.

The results are summarized as follows;

1) The amplification factor decreases with the non-uniformity of field increased.

2) Near the cyclotron resonance point, the anomalous damping of the excited wave is observed. This damping can be explained as the cyclotron damping of the longitudinal wave propagating obliquely to the line of magnetic force.

References

1) R.J. Briggs; Electron-Stream Interaction with Plasma,M.I.T. Press, Cambridge, Massachusetts (1964).

2) T. Idehara, M. Takeda and Y. Ishida; J. Phys. Soc. Japan 39 (1975) 213.

3) I.B. Bernstein; Phys. Rev. 109 (1958) 10.

4) A.W. Trivelpiece and R.W. Gould; J. Appl. Phys. 30 (1959) 1784.